REC-ERC-82-6

LIMNOLOGY OF MT. ELBERT FOREBAY—1978-79

March 1982

Engineering and Research Center

U.S. Department of the Interior

Bureau of Reclamation

7-2090 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
REC-ERC-82-6		

4. TITLE AND SUBTITLE
Limnology of Mt. Elbert Forebay–1978-79

5. REPORT DATE
March 1982

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
John R. Boehmke, James F. LaBounty,
James J. Sartoris, and Richard A. Roline

8. PERFORMING ORGANIZATION REPORT NO.
REC-ERC-82-6

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Bureau of Reclamation
Engineering and Research Center
Denver CO 80225

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
Same

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE
DIBR

15. SUPPLEMENTARY NOTES
Microfiche and/or hard copy available at the E&R Center, Denver, Colo.

Ed:RNW

16. ABSTRACT
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The forebay was found to be higher in dissolved substances and nitrogen and phosphorus compounds, but lower in abundance of plankton and benthic organisms than the afterbay (Twin Lakes). A possible cause of lesser abundance of organisms is higher concentrations of iron and zinc that were found in Mt. Elbert Forebay.

Limnological studies in the future will continue investigations of Mt. Elbert Forebay and Twin Lakes to determine ecological effects of pumped-storage operation.

17. KEY WORDS AND DOCUMENT ANALYSIS
a. DESCRIPTORS-- / *reservoirs/ plankton/ ecology/ *limnology/ *environmental effects/ powerplants/ pumped storage/ physical factors/ aquatic habitats/ chemical factors/ biological factors/ temporary reservoirs/

b. IDENTIFIERS-- / Twin Lakes, Colo./ Fryingpan-Arkansas Proj., Colo./ Mt. Elbert Forebay Dam, Colo./

c. COSATI Field/Group 06F *COWRR:* 0606 *SRIM:*

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
Available from the National Technical Information Service, Operations Division, 5285 Port Royal Road, Springfield, Virginia 22161. (Microfiche and/or hard copy available from NTIS)	*UNCLASSIFIED*	23
	20. SECURITY CLASS (THIS PAGE)	22. PRICE
	UNCLASSIFIED	

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LIMNOLOGY OF MT. ELBERT FOREBAY—1978-79

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Denver, Colorado

SI METRIC

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

ACKNOWLEDGMENTS

This report was developed as a part of the Bureau of Reclamation's Twin Lakes Ecological Study, which is being performed under supervision of N. E. Otto, Head, Environmental Sciences Section, and L. O. Timblin, Jr., Chief, Applied Sciences Branch. The study is a cooperative effort involving the Bureau of Reclamation, Colorado Division of Wildlife, and Fish and Wildlife Service's Colorado Cooperative Fishery Research Unit at Colorado State University, Fort Collins, Colo. Partial funding and field support were provided by the Bureau's Lower Missouri Region and the Fryingpan-Arkansas Project of the Bureau of Reclamation.

The Bureau's Division of Research; Chemistry, Petrography, and Chemical Engineering Section, provided laboratory chemical analyses for the the study. S. G. Campbell and S. D. Hiebert of the Division of Research; Applied Sciences Branch, assisted in the biological analyses.

Some data in this report were measured in inch-pound units and converted to SI units.

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APPLICATION

Results of this investigation will be of interest to anyone involved in studying lake ecosystems — particularly temporary impoundments in mountainous regions. Physical, chemical, and biological data obtained in this study will be used with similar data from Twin Lakes, Colorado, to determine the effects of construction and operation of Mt. Elbert Forebay and Pumped-Storage Powerplant on the aquatic environment. This study provides baseline data to help determine environmental effects of a new chlorinated polyethylene liner installed in Mt. Elbert Forebay.

SUMMARY

The Mt. Elbert Forebay and Pumped-Storage Powerplant was studied from November 1978 through September 1979. It was found to be a cold monomictic impoundment that was filled initially in the fall of 1978. In the fall of 1979, the forebay was drained to install a buried CPE (chlorinated polyethylene) liner to prevent seepage.

Mt. Elbert Forebay was found to be higher in dissolved substances and nitrogen and phosphorus compounds, but lower in abundance of plankton and benthic organisms than the afterbay (Twin Lakes). A possible cause of lesser abundance of organisms is higher concentrations of iron and zinc that were found in Mt. Elbert Forebay.

In the future, limnological studies will be continued on the forebay and Twin Lakes to determine ecological effects of pumped-storage operation.

INTRODUCTION

Pumped-storage powerplants store energy for later use in the power grid. Under normal operation, water is pumped to a higher elevation during periods of low power demand and released for power generation during peak demand. Although there is an overall power loss for operation of a pumped-storage powerplant, their ability to level fluctuations of the power curve increases the efficiency of the total power generation system. Pumped storage allows thermo powerplants to operate more efficiently at constant loads. The reservoir at a higher elevation used for storage is called the powerplant forebay. The forebay for Mt. Elbert Pumped-Storage Powerplant (fig. 1) is located about 137 meters above Twin Lakes. Prior to Mt. Elbert Forebay construction, the area consisted of sagebrush, sandy soil, and stands of aspen trees (fig. 2), and was used as an elk wintering ground.

Construction of the forebay began in 1975 and was completed the following year. The constructed bottom was a 1.5-meter-thick compacted sandy-silt liner; however, in the fall of 1980, a CPE liner was added to decrease seepage (Morrison, et al., 1981 [1]).[1]

In 1977-78, the forebay was filled originally to a maximum depth of 8 meters (19 percent total capacity) with water pumped from Twin Lakes. Throughout the duration of this limnological study, the forebay had neither an inlet nor an outlet. Precipitation was the only water introduction. In the fall of 1979, water was drained back into Twin Lakes to allow the installation of the CPE liner.

When the system is placed into operation, water from Turquoise Reservoir (Sugar Loaf Dam) will flow through Mt. Elbert Conduit, a 2275-mm-dia., 17.2-km-long conduit into the north end of Mt. Elbert Forebay. Water and biota from the two systems (Twin Lakes on Lake Creek and Turquoise Reservoir on the Lake Fork of the Arkansas River) then will be mixed in the forebay during the initial pumping cycles. During successive generating cycles, water will flow into Twin Lakes. An understanding of what comes into the forebay and what occurs limnologically in the forebay is important in evaluating the effects of the powerplant on the ecology of Twin Lakes. Understanding the data collected during the 1-year existence of the original constructed forebay during 1978-79 will provide insight for future studies of that impoundment.

The 1978-79 limnological study of Mt. Elbert Forebay was done in conjunction with other limnological studies at Twin Lakes. The purpose of the overall study is to determine the effects

[1] Numbers in brackets refer to the bibliography.

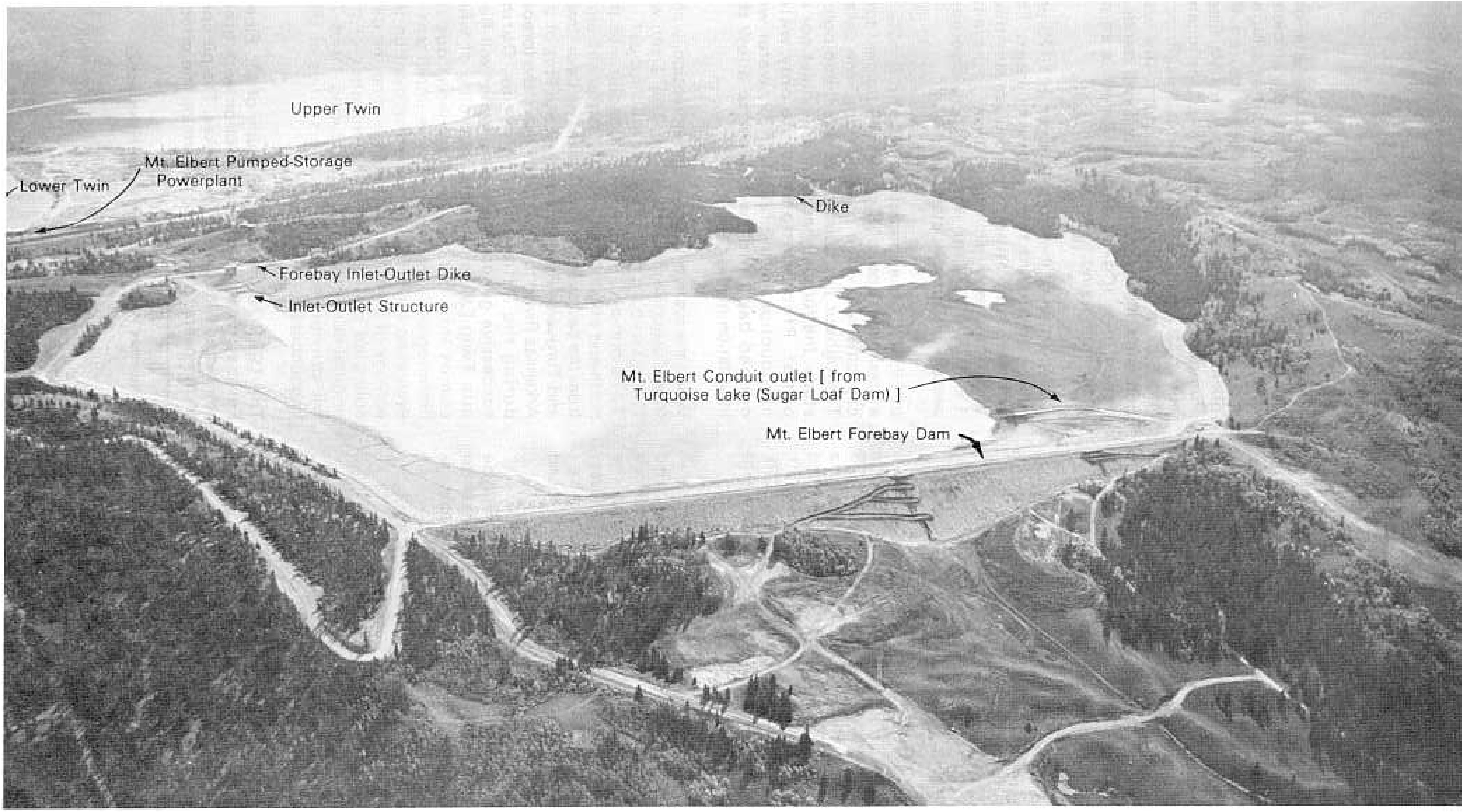

Figure 1.—Mt. Elbert Pumped-Storage Powerplant and Forebay Dam, Fryingpan-Arkansas Project. View looking southwest toward Twin Lakes, Colorado–September 20, 1979. P801-D-79698

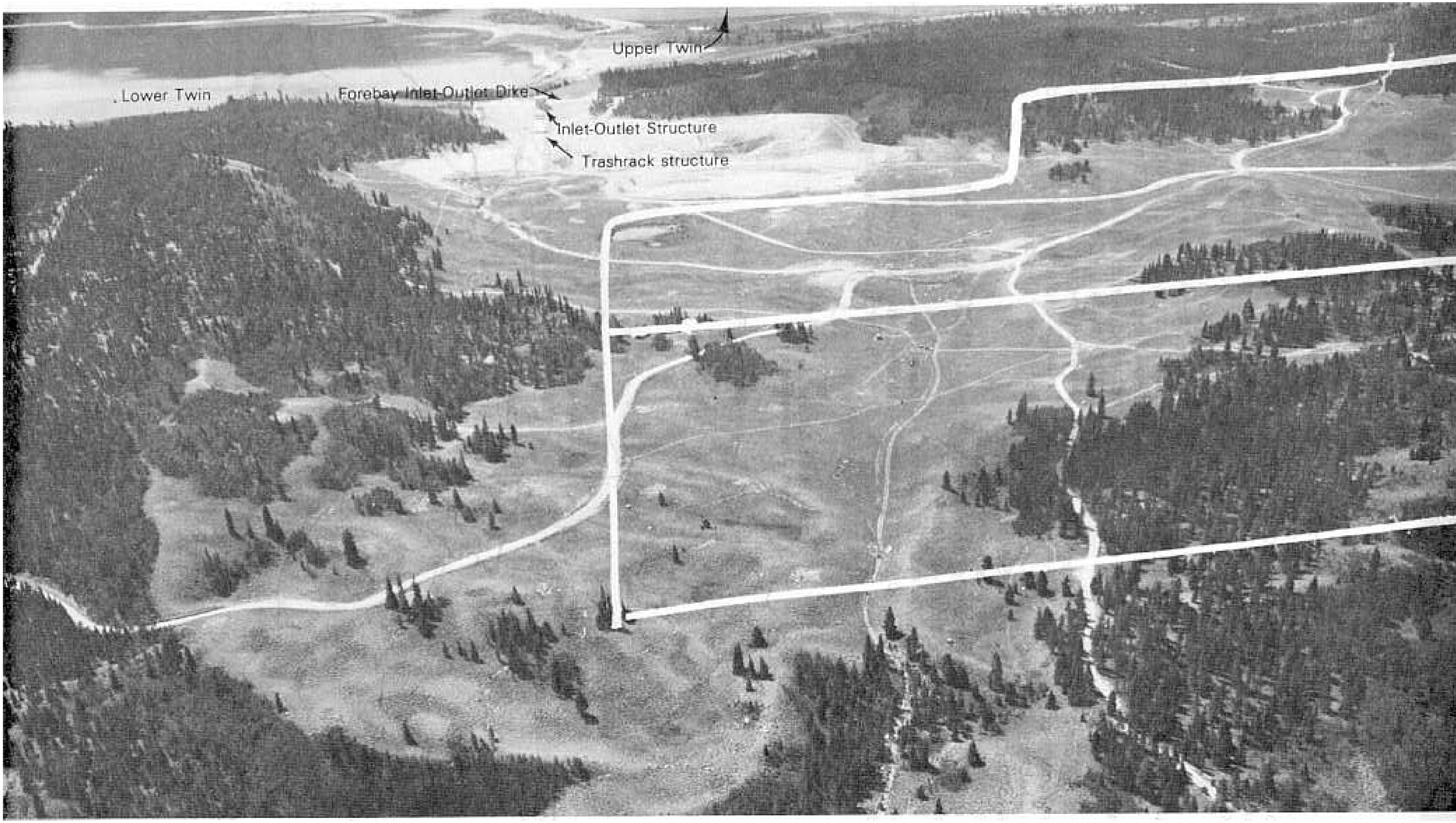

Figure 2.—Mt. Elbert Forebay Dam site before construction. Garner and Hallenbeck mining claims are indicated by white perimeters August 14, 1975.
P801-D-79699

of pumped storage on the aquatic environment of Twin Lakes. Information will help maximize ecological resources while meeting the water storage and power generation objectives of Fryingpan-Arkansas Project.

DESCRIPTION OF THE STUDY AREA

Location

The Mt. Elbert Forebay is situated on a lateral moraine, north of Twin Lakes, Colorado, and the Lake Creek drainage (fig. 3). Lake Creek is located at the eastern foot of the Sawatch Range in the upper Arkansas River Valley of central Colorado. The present topography of the western side of the Arkansas River Valley in the Lake Creek area is largely the result of glacial action on earlier alluvial deposits (Buckles, 1973)[2].

Morphometry

The bottom topography and shoreline of the Mt. Elbert Forebay are shown on figure 4. The maximum water surface elevation is 2940 meters above mean sea level. At this elevation, the lake surface area is 115 hectares, having a total capacity of 14 234 000 cubic meters, and an average depth of 13 meters. During the sampling period, the lake surface elevation was 2926 meters above mean sea level. At this elevation, the lake surface area was 47 hectares, having a capacity of 2 716 000 cubic meters, and an average depth of nearly 6 meters.

METHODS AND MATERIALS

Monthly and semimonthly surveys were conducted at Mt. Elbert Forebay from November 1978 through September 1979. Table 1

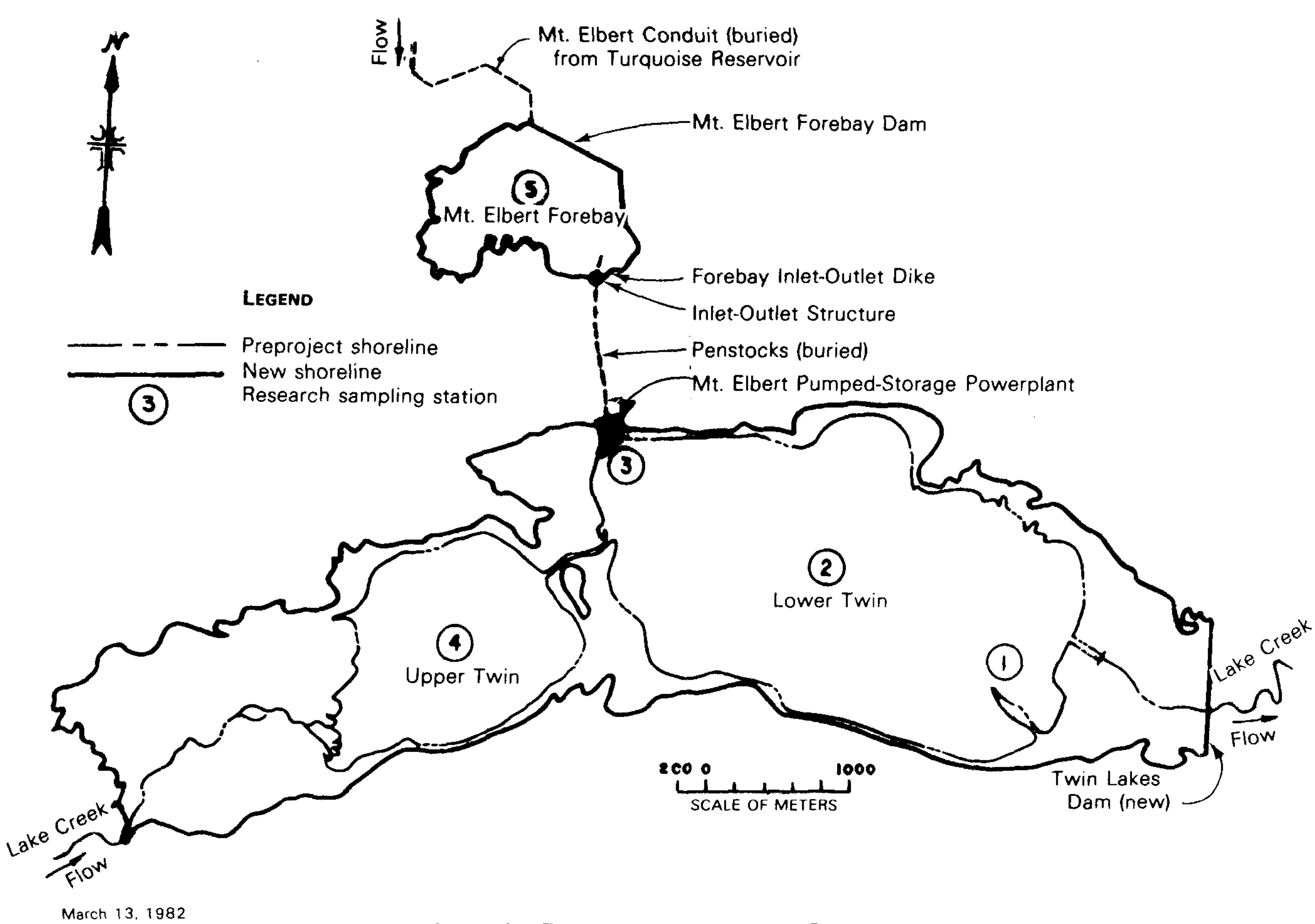

Figure 3.—Twin Lakes and Mt. Elbert Forebay.

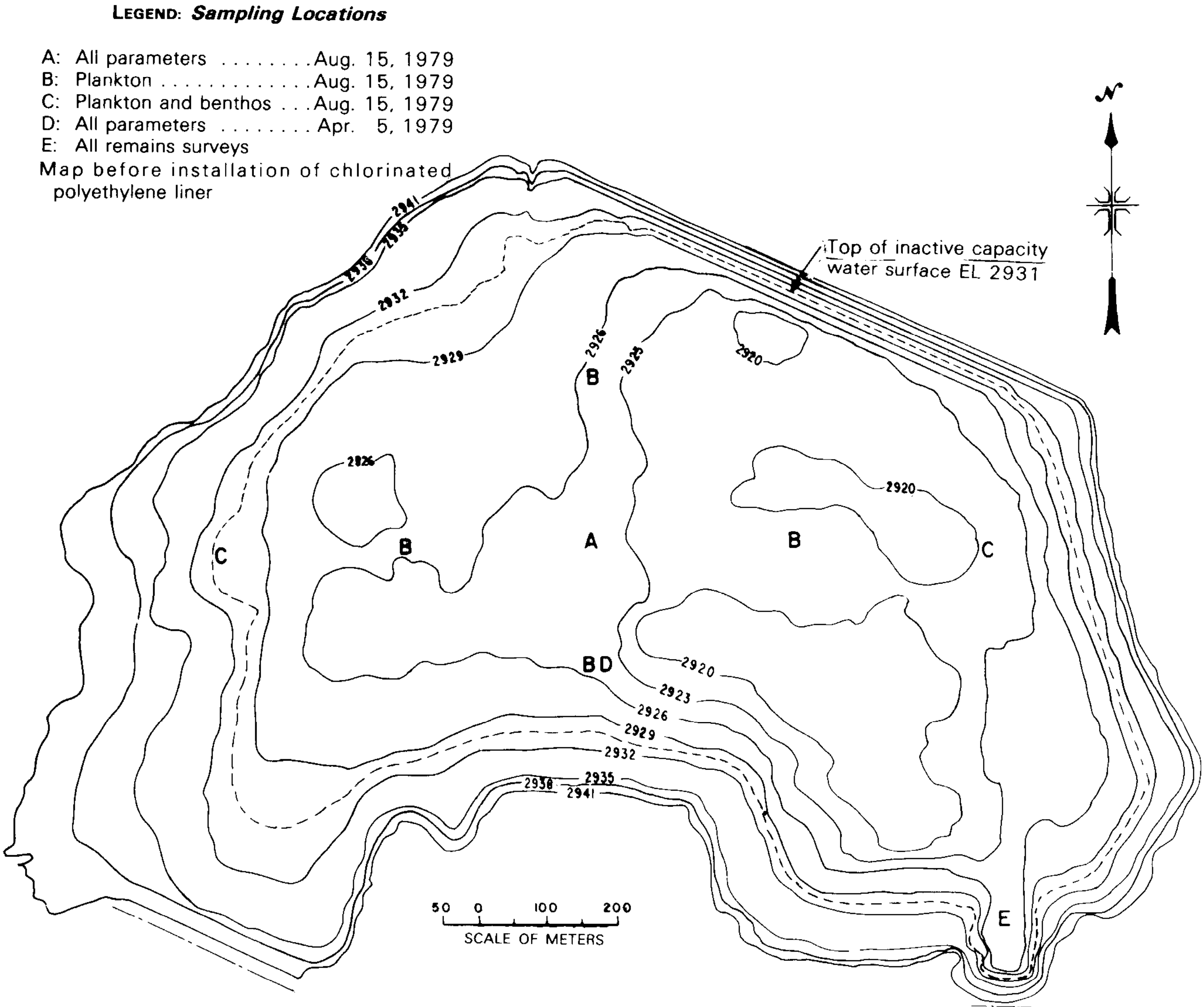

Figure 4.—Morphometric map of Mt. Elbert Forebay showing sampling locations.

summarizes dates and parameters of the surveys. Figure 4 shows the locations of the sampling stations. The following is a brief description of the methods used to measure each of the parameters listed in table 1.

Physical-Chemical Factors

Temperature, dissolved oxygen, conductivity, pH (hydrogen-ion concentration), and ORP (oxidation-reduction potential) were measured with an electronic multiparameter probe. Water samples were collected from the surface or from depths of 1 and 3 meters using a Van Dorn style water sampler. The samples were analyzed for the following constituents:

- Major ions,
- Trace metals (copper, zinc, iron, manganese, and lead), and
- Plant nutrients (orthophosphate, total phosphate, total Kjeldahl nitrogen, nitrate nitrogen, nitrite nitrogen, and ammonia).

Samples for the trace metal analysis were preserved immediately after collection with 1 milliliter of concentrated nitric acid per 230 mL of water. Samples for nutrient analysis were frozen immediately following collection. All samples were analyzed according to standard procedures.[2]

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[2] *National Handbook of Recommended Methods for Water Data Aquisition*, Geological Survey, U.S. Dept. of the Interior, Reston, Virginia, 1977.

Table 1.—*Summary of dates and kinds of data obtained from Mt. Elbert Forebay. Twin Lakes, Colorado 1978-1979*

Date	Note*	Chemical constituents	Chlorophyll	Plankton	Benthos
1978					
Nov. 3		X	X	X	
Nov. 16		X	X	X	
Dec. 1		X		X	
Dec. 20		X		X	
1979					
Jan. 11		X		X	
Feb. 2		X		X	
Feb. 21		X		X	
Mar. 13		X		X	
Apr. 5	X	X		X	X
Apr. 19		X		X	
May 16		X			
June 6		X			
June 22		X	X	X	
July 5		X		X	
July 19		X	X	X	
Aug. 3		X	X	X	
Aug. 15	X	X	X	X	X
Sept. 7		X		X	
Sept. 14		X			
Sept. 21		X			

* Note: This column is: temperature, dissolved oxygen, pH, conductivity, oxidation reduction potential, and profiles.

Chlorophyll

Water samples for chlorophyll analysis were collected from 0.1-, 1.0-, and 3.0-meter depths except in November 1978 when only surface (0.1-m) samples were collected. Following collection, 800-mL samples were filtered through millipore glass filter pads. Chlorophyll extraction and analysis were done according to methods outlined in Parsons and Strickland (1963)[3].

Phytoplankton and Zooplankton

Plankton were collected by two different methods. The January 11, 1979, collections were made by pouring water from a Kemmerer water sampler (2000 mL) through a No. 20 silk student net. The remainder of the collections were made using a No. 20 (mesh opening equals 76 micrometers) silk net and bucket. Vertical hauls were made from the bottom to the surface. The samples were preserved using a 2-percent formalin solution for laboratory analysis. Laboratory methods followed those of Welch (1948)[4].

Benthos

Three samples of benthic muds were collected from each station using a Ponar dredge. These samples were filtered through a 600-μm sieve (ASTM Standard No. 30) and then preserved in a 10-percent formalin solution for laboratory analysis. All specimens were identified according to type, and then counted and weighed. Both the wet and dry biomass were obtained using methods found in APHA (1975)[5].

RESULTS

Physical Limnology

Ice covered the Mt. Elbert Forebay from November 1978 through April 1979. Figures 5 and 6 show data on ice and snow cover during the 1978-79 winter season. Maximum ice thickness measured was 740 mm on April 5, 1979. Maximum snow depth was 460 mm on March 13, 1979. During the same period, ice covered Twin Lakes from December 20, 1978, until May 15, 1979. Maximum ice thickness was 790 mm on April 4, 1979. Maximum snow depth was recorded as 250 mm on February 21, 1979.

Water surface temperatures in the forebay ranged from 0 °C during the winter to 16.5 °C on August 15, 1979. Water surface temperatures of Twin Lakes ranged from 0 to 16.6 °C during the same period.

Two temperature profiles were measured in the forebay, in April and August. The April profile showed a winter inverse stratification under the ice having a surface temperature of 1.4 °C and a bottom temperature of 3.8 °C. The August profile was isothermal at 16.5 °C. These results indicate that the forebay could be categorized as cold monomictic.

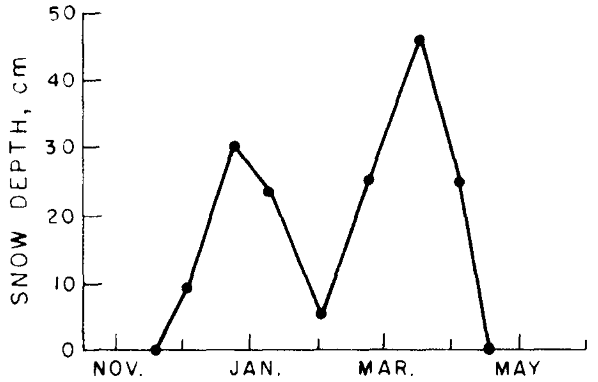

Figure 5.—Snow depth measured at Mt. Elbert Forebay—during 1978-79.

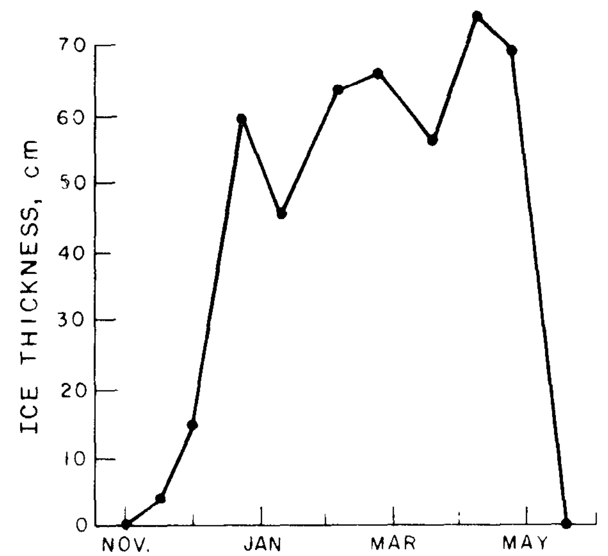

Figure 6.—Ice thickness on Mt. Elbert Forebay—measured during 1978-79.

Electrical conductivity of the forebay surface waters (fig. 7) averaged 101 μS/cm with a range of 85 μS/cm to 118 μS/cm. During the same period, Twin Lakes averaged 66 μS/cm and ranged from 48 to 81 μS/cm. The higher average conductivity of the forebay may be caused by either the effects of evaporation or the dissolution of solids when the forebay was filled.

Water in the forebay was essentially stagnant for a year as a result of no inflow nor outflow.

Electrical conductivity profiles were measured in April and August. The April profile was slightly stratified having 109 μS/cm at the surface and 104 μS/cm at the bottom. The August profile was stratified with 95 μS/cm at the surface and 76 μS/cm at the bottom.

Chemical Limnology

Table 2 and figures 8 and 9 show a summary of data collected on the chemical limnology of Mt. Elbert Forebay. Table 2 includes the maximum, minimum, and average values for 20 sampling dates. Specific data are in the appendix. The average TDS (total dissolved solids) in the forebay was 68 mg/L. The major cation was — by far — calcium (average equals 13.9 mg/L). The major anions were bicarbonate and sulfate (average equals 37.0 and 15.9 mg/L, respectively). Heavy metals concentrations in the forebay were relatively high with iron being the highest (average equals 0.324 mg/L). Generally, the nitrogen-phosphorus nutrients were all higher than concentrations in Twin Lakes. Phosphorus was especially more abundant.

Figure 8 shows phosphate data versus time. There is little trend to the total phosphorus data. However, orthophosphate does show up in detectable amounts during the middle of winter. Figure 9 presents nitrogen data versus time. Concentrations of TKN were greatest during March and midsummer. Concentrations of nitrate show a cycle versus time. Low concentrations occurred during early winter and midsummer. The highest concentrations occurred just after ice-off. Nitrate concentrations declined sharply in the fall.

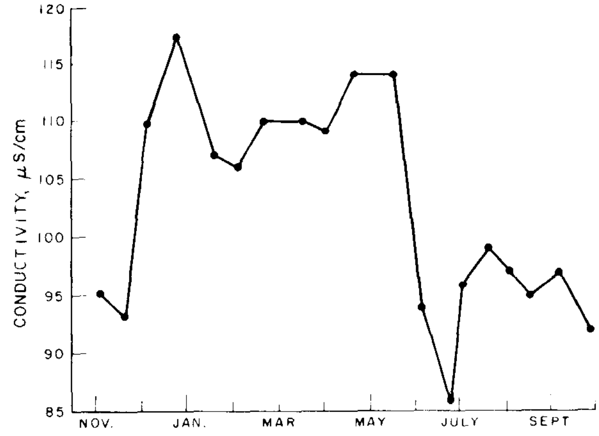

Figure 7.—Surface conductivity measurements—Mt. Elbert Forebay 1978-79.

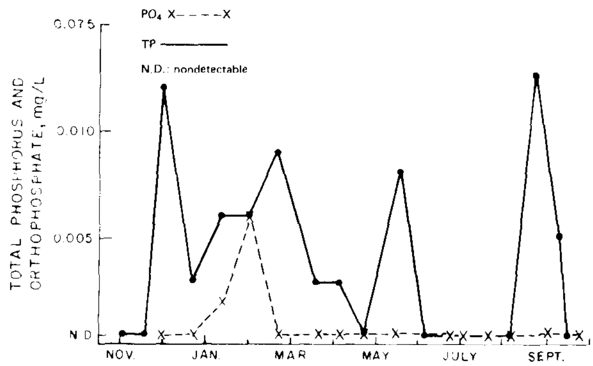

Figure 8.—Total phosphorus and orthophosphate concentration versus time—Mt. Elbert Forebay 1978-79.

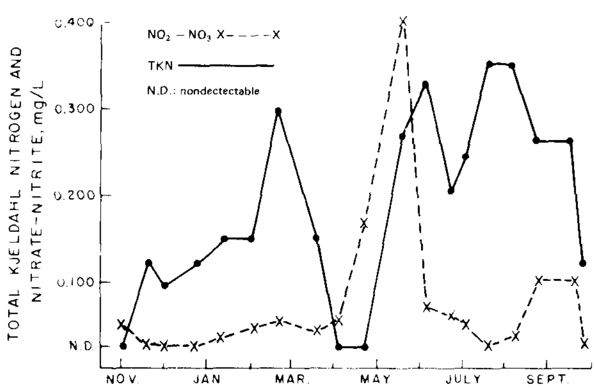

Figure 9.—Total Kjeldahl nitrogen and nitrate-nitrite versus time—Mt. Elbert Forebay 1978-79.

Table 2.—*Averages of 22 chemical analyses. Mt. Elbert Forebay, Twin Lakes, Colorado, 1978-79*

Chemical	Maximum, mg/L	Minimum, mg/L	Average,* mg/L
Calcium	16.0	12.2	13.9
Magnesium	3.9	0.2	1.9
Sodium	3.2	1.8	2.3
Potassium	2.4	0.8	1.9
Carbonate	0	0	0
Bicarbonate	56.7	30.5	37.0
Sulfate	19.7	10.1	15.9
Chloride	2.8	0.4	1.9
Total dissolved solids	102.0	50.0	68.0
Copper	0.500	<0.001	0.009
Iron	0.80	<0.10	0.324
Lead	0.20	<0.001	0.016
Manganese	0.05	<0.01	0.005
Zinc	0.430	<0.001	0.025
Total phosphorus	0.012	<0.001	0.008
PO_4-P (orthophosphate)	0.015	<0.001	0.0016
NH_3 (ammonia)	0.040	<0.010	0.020
NO_3 (nitrate)	0.400	<0.001	0.060
NO_2 (nitrite)	0.010	<0.001	0.0018
TKN (total Kjeldahl nitrogen)	0.420	<0.010	0.172

* One half the detection limit is used for nondetectable values when computing averages.

Biological Limnology

Chlorophyll.–Chlorophyll samples were taken on six sampling dates. Table 3 presents concentrations that were found. The higher concentrations were found generally in the lower depths. The highest values were recorded during mid-August.

Phytoplankton.–Phytoplankton data are shown on figures 10 and 11. The total number of organisms peaked in late November before dropping to near zero from late December (1978) through early February. The remainder of the year indicated a series of three smaller increases and declines in abundance.

The composition of genera went through several changes throughout the study. In November and December (1978), the dominant genera was found to be *Asterionella* . There were not detectable phytoplankton populations during January and early February (1979). *Asterionella* and *Dinobryon* appeared in equal numbers in late February. After another decline in March and early April, the phytoplankton shifted to a *Synedra*-dominated community. During July and early August, the forebay was host to a more diverse phytoplankton community. By the middle of August, the dominance of *Synedra* was again in evidence.

Table 4 shows ranges and averages of genera found. Detailed abundance data can be found in the appendix.

Zooplankton.–Zooplankton data are shown on figures 12 and 13. The total abundance of organisms showed a slight peak in late November 1978, remained low through May, hit

Table 3.—*Chlorophyll* a *concentrations. Mt. Elbert Forebay, Twin Lakes, Colorado, 1978-79*

Date	Surface, µg/L	1 m deep, µg/L	3 m deep, µg/L
1978			
Nov. 3	0.77	–	–
Nov. 16	0.71	–	–
1979			
June 22	0.43	0.52	0.34
July 19	0.87	1.15	1.32
Aug. 3	0.56	0.56	0.71
Aug. 15	1.41	1.55	1.88

Table 4.–*Average and range of phytoplankton. Mt. Elbert Forebay, Twin Lakes, Colorado, 1978-79*

Genus	Average No./L	Range No./L
Asterionella	42.2	0 to 238
Synedra	9.8	0 to 51
Dictospherum	8.5	0 to 108
Dinobryon	3.8	0 to 41
Oscillatoria	2.8	0 to 15
Fragilaria	1.5	0 to 10

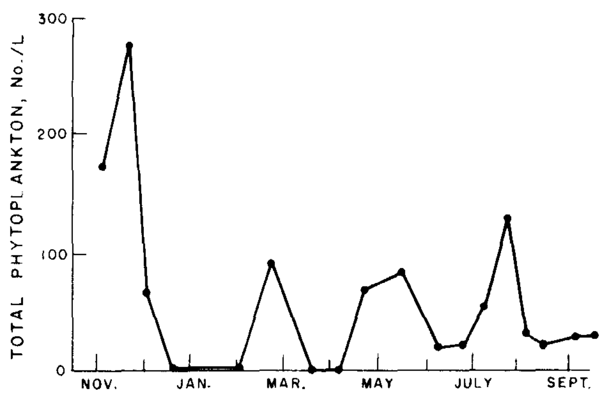

Figure 10.—Total abundance of phytoplankton versus time—Mt. Elbert Forebay 1978-79.

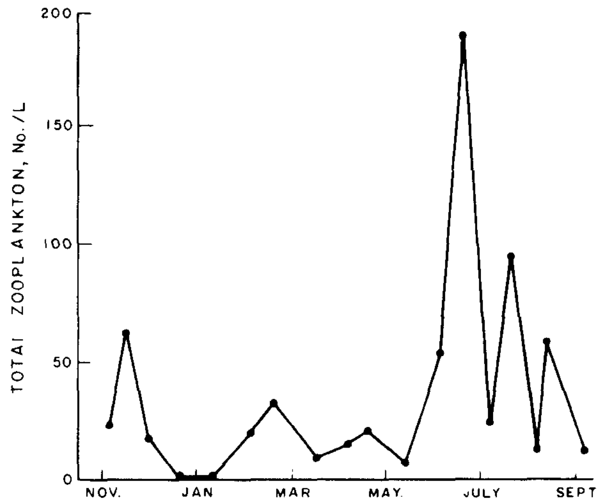

Figure 12.—Total abundance of zooplankton versus time—Mt. Elbert Forebay 1978-79.

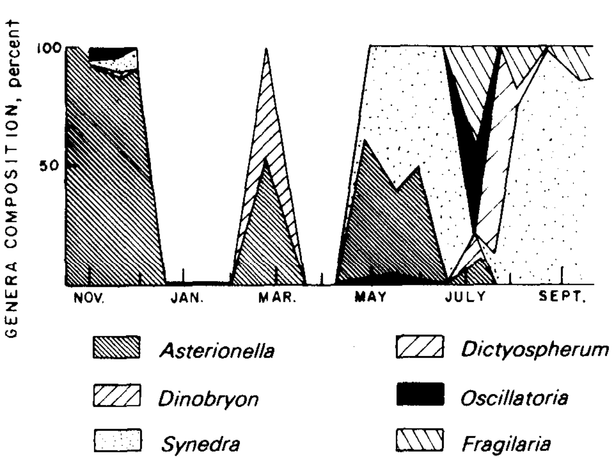

Figure 11.—Percentage genera composition versus time—Mt. Elbert Forebay 1978-79.

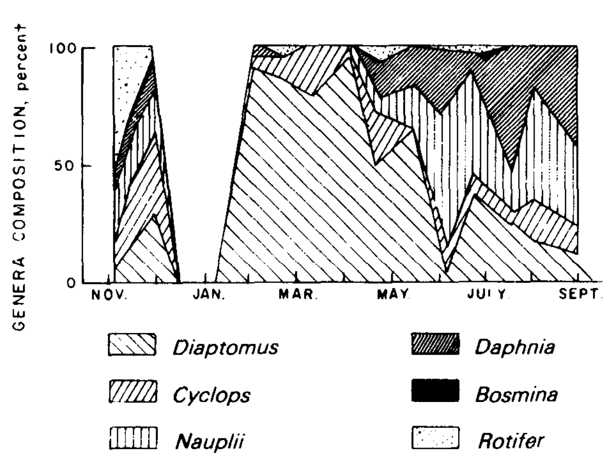

Figure 13.—Percent zooplankton genera composition versus time—Mt. Elbert Forebay 1978-79.

a substantially higher peak in later June, and then tapered off through the early fall. Dominant forms, during June when the peak occurred, were *Diaptomus* and unidentified nauplii.

Like the phytoplankton, the zooplankton population also declined to zero from late December through early February. During November and early December 1978 — before this decline — zooplankters formed a diverse community. After the decline, *Diaptomus* was dominant throughout the summer until late July when the numbers of *Daphnia* became more significant.

Table 5 shows ranges and averages of genera found. Detailed abundance can be found in the appendix.

Table 5.–*Average and range of zooplankton Mt. Elbert Forebay. Twin Lakes, Colorado, 1978-79*

Genus	Average No./L	Range No./L
Diaptomus	13.5	0 to 70
Copepod Nauplii	10.3	0 to 106
Daphnia	4.6	0 to 49
Cyclops	3.3	0 to 16
Polyarthra	2.4	0 to 21
Kellocottia	0.4	0 to 2
Keratella	0.2	0 to 2
Bosmina	0.1	0 to 1

Benthos.–Benthic sampling was done twice — first on April 5, 1979, and second on August 15, 1979. The results from the April sampling showed 43 chironomids per square meter having a dry mass of 6.9 milligrams per meter square, and 43 oligochaetes per square meter and dry mass of 9.9 mg/m². The August sampling results showed 153 chironomids per meter square at a dry mass of 13.66 mg/m².

DISCUSSION

This study of the preoperational limnological conditions of Mt. Elbert Forebay was undertaken to provide a source of baseline data for which future conditions could be evaluated. Further studies of the forebay will deal with its interactions with Twin Lakes environment after the powerplant is in operation. During 1978-79, Mt. Elbert Forebay cound be considered a unique temporary impoundment because of its large size (47 hectares), capacity (2 716 000 m³), and average depth (6 m). Comparisons to work done by others on temporary ponds were deemed inappropriate because of large disparities in impoundment morphology.

Physical and Chemical Properties

The discussion of physical and chemical properties of the forebay will consist mainly of a comparison of its limnological parameters with those of Twin Lakes during the same time period. The reason for this is to determine reactions of both bodies of water to the same physical conditions so that future ecological interactions between the two may be better understood.

Snow and ice covered both Twin Lakes and the forebay during the winter months as expected for lakes at this latitude and altitude. Ice cover was reported nearly one month earlier on the forebay, commencing during mid-November. The can be explained by the shallower depth and smaller capacity of the forebay as compared to Twin Lakes. It allowed for quicker dissipation of heat from water. Both bodies of water achieved maximum ice thickness early in April and averaged about 500 millimeters.

Snow covered the ice on both forebay and Twin Lakes from December through April, although local conditions at sampling locations make quantitative comparisons meaningless. Proximity of the forebay sampling location to a floating raft at the penstock inlet-outlet structure (fig. 15), and the topography of the nearby shore, created totally different conditions for drifting and blowing snow than were present at the sampling location in the middle of Twin Lakes. Therefore, the 50-percent greater average snow depth at the forebay sampling location is probably due to drifting snow and cannot be attributed to a difference in meteorological conditions.

Surface water temperature readings were taken on nine of the sampling dates. Values ranged from 0 °C — immediately under the ice — to 16.5 C in mid-August. Two temperature profiles

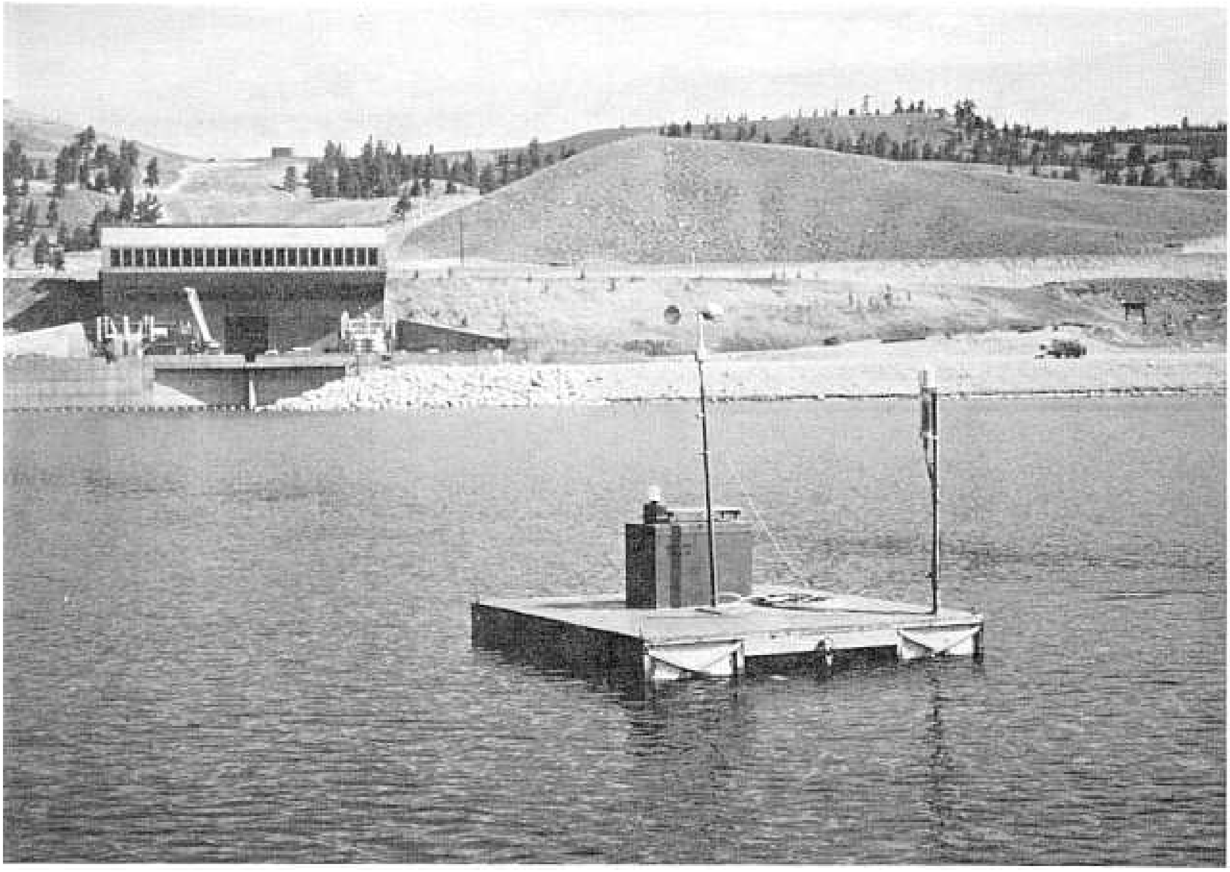

Figure 14.--Looking north at the instrumentation raft at station 3 of Twin Lakes. Mt. Elbert Pumped-Storage Powerplant is on the shoreline. P801-D-79700

were done, one through the ice in April and one in mid-August. The winter profile showed a winter inverse stratification, but the August profile indicated that water was mixing because of its shallowness and wind action. During the same period, Twin Lakes reached a maximum surface temperature of 16.6 °C in mid-August. The profile done in Twin Lakes at this time showed a stong stratification having a bottom temperature of 8.4 °C. This stratification allowed the epilimnion to heat up so that the maximum surface temperatures in Mt. Elbert Forebay and Twin Lakes were nearly identical even though Twin Lakes has greater depth and volume.

As with all waters in this watershed, Mt. Elbert Forebay is relatively dilute — always having conductivity values below 120 μS/cm. The average forebay conductivity of 101 μS/cm is slightly higher than the 68 μS/cm of Twin Lakes, presumably from an increase of dissolved solids derived from the initial inundation of the forebay substrate and possibly due to concentration by freezing and evaporation in the essentially stagnant impoundment.

Table 6 compares the average heavy metals concentrations in the forebay and Twin Lakes.

Table 6 shows heavy metals data from Mt. Elbert Forebay and Twin Lakes. Samples collected for analyses from both locations were not filtered, thus, particulate and dissolved concentrations are not known. However, since dissolved oxygen was always present and the pH was always well above 7.0, it seems unlikely that the heavy metals are dissolved, thus, biologically of little importance. From the data, it is noted that all metals — except manganese — are found in higher concentrations in the Mt. Elbert Forebay than in Twin Lakes. Copper concentrations in the

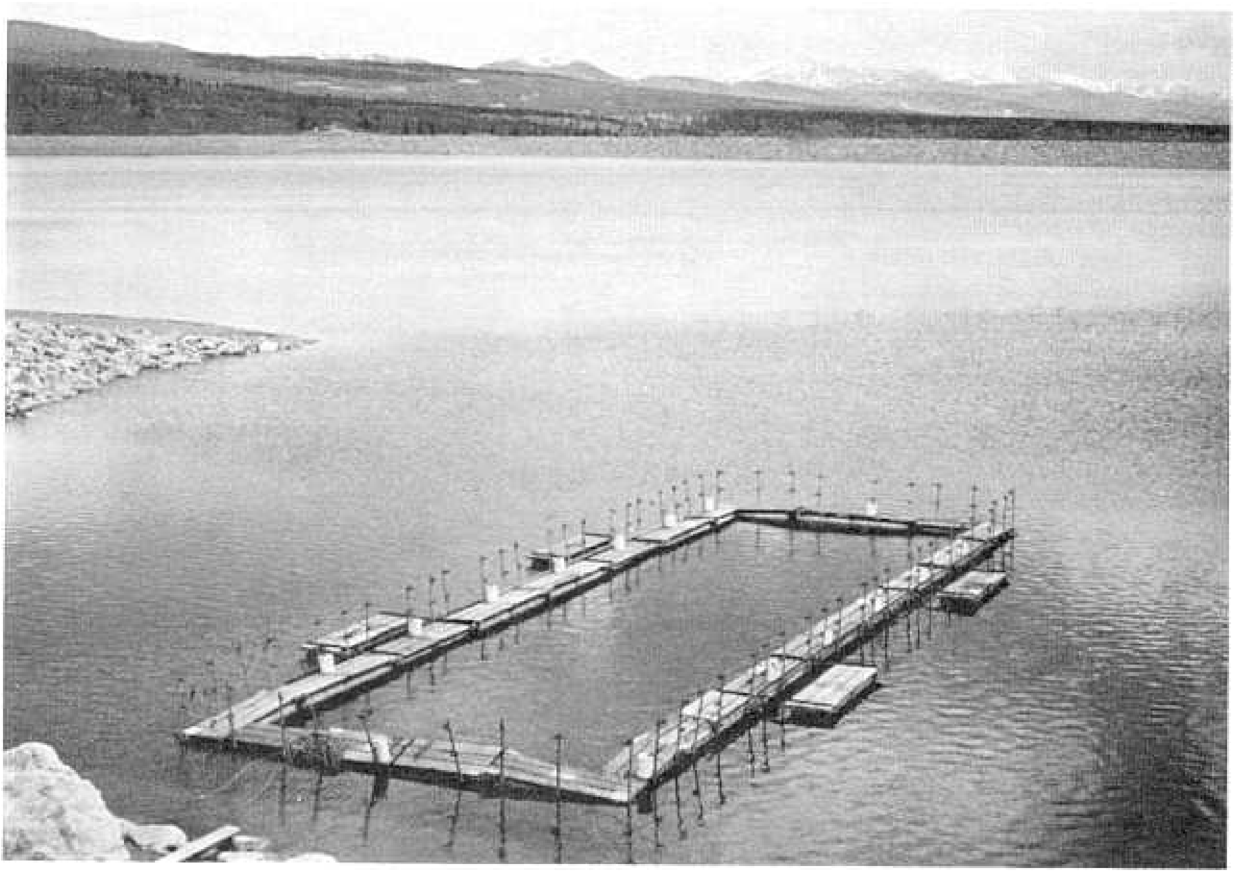

Figure 15.—Looking northwest across Mt. Elbert Forebay. The raft system in the foreground will be used in fish collection. It is located in the inlet-outlet channel. P801-D-79701

Table 6.–*Heavy metals comparisons between Mt. Elbert Forebay and Twin Lakes. Twin Lakes, Colorado, 1978-79*

Metal	Twin Lakes average mg/L	Mt. Elbert Forebay average, mg/L
Copper	0.0028	0.0085
Iron	.078	.32
Lead	.0028	.0071
Manganese	.0097	.005
Zinc	.0029	.025

forebay exceeded Twin Lakes by 3 times, iron by 4 times, lead by 2.5 times, and zinc by 8.6 times. Because the original source of forebay water was Twin Lakes, this increase of heavy metals concentrations is caused by inundation of substrate, allochthonous input from runoff, and concentration due to evaporation.

Table 7 compares major ionic composition of the Mt. Elbert Forebay and Twin Lakes. The principal cation is calcium and the principal anions are bicarbonate and sulfate. From table data, one notes that the forebay averaged approximately 1.5 times greater than Twin Lakes in concentrations of ions. This increase in ions is from inundation of forebay substrate, allochthonous input from local runoff, and concentration caused by evaporation. According to the classification by Hart, et al., 1945[6], the forebay — based on freshness — ranks among the best 5 percent of waters in the United States that support good fish populations.

Table 8 compares the nutrient concentrations of the forebay and Twin Lakes. Table data show that the forebay has about twice the total

Table 7.–*Comparison of major ions of Mt. Elbert Forebay and Twin Lakes. Twin Lakes, Colorado, 1979*

Ion	Twin Lakes average, mg/L	Mt. Elbert Forebay average, mg/L
Calcium	8.80	13.85
Magnesium	1.55	1.87
Sodium	1.23	2.27
Potassium	0.89	1.88
Carbonate	0	0
Bicarbonate	23.4	37.0
Sulfate	9.92	15.9
Chloride	2.37	1.86
Total dissolved solids	48	68

Table 8.–*Nutrient concentration of Mt. Elbert Forebay and Twin Lakes. Twin Lakes, Colorado, 1979*

Nutrient	Twin Lakes average, mg/L	Mt. Elbert Forebay average, mg/L
Total phosphorus	0.003	0.004
Ammonia	.013	.019
Nitrate	.017	.052
Total Kjeldahl nitrogen	.09	.172

nitrogen but nearly the same concentration of total phosphorus. All values are relatively low. Like Twin Lakes, the forebay appears to be oligotrophic and probably phosphorus limited.

Biological Properties

The Mt. Elbert Forebay and Twin Lakes were more dissimilar biologically than they were chemically or physically. Phytoplankton, zooplankton, chlorophyll, and benthos were all less abundant in the forebay.

Total phytoplankton concentrations were more than 100 times greater in Twin Lakes than in the forebay. Table 9 compares the average phytoplankton concentrations.

Table 9.–*Phytoplankton concentration of Mt. Elbert Forebay and Twin Lakes. Twin Lakes, Colorado, 1979*

Phytoplankton, genus	Twin Lakes average, No./L	Mt. Elbert Forebay average, No./L
Dictyospherum	151	8.5
Asterionella	1677	42.2
Oscillatoria	9.1	2.8
Synedra	2063	9.8
Dinobryon	3224	3.8
Fragilaria	0	1.5
Total	7124	68.6

The phytoplankton forebay population peaked in late November with minor peaks in February, May, and July. The general composition shifted from 100 percent *Asterionella* in November to 100 percent *Synedra* in August. During the same period, Twin Lakes peaked also in November and had a minor peak in May. The genera composition in Twin Lakes changed from *Dinobryon* domination in November and December (1978) to an *Asterionella* domination in February, March, and April (1979) and finally to a domination by *Synedra* in July, August, and September (1979).

The great disparity in phytoplankton concentrations is the most noticeable difference between the two bodies of water. With similarity in water temperature (upper depths), nutrient concentrations, and solar input (because of their close proximity), this difference cannot be explained. It may be that turbidity in the forebay did not allow as great a light penetration as in Twin Lakes.

Zooplankton concentration also show a greater number in Twin Lakes (table 10), although the difference is not of the magnitude found in phytoplankton. This difference can be attributed directly to a decreased abundance of food (phytoplankton) available in the forebay. The lack of cladocerans in Twin Lakes is presumed to be caused by predation upon them by freshwater shrimp *(Mysis relicta)* present in Twin Lakes but not yet collected from the forebay.

Chlorophyll *a* concentrations — as would be expected from the phytoplankton data — were greater in Twin Lakes. Average chlorophyll concentrations during the study period in Twin Lakes were 4.45 mg/L versus 0.93 mg/L in the forebay.

Table 10.–*Zooplankton concentration of Mt. Elbert Forebay and Twin Lakes. Twin Lakes, Colorado, 1979*

Zooplankton, genus	Twin Lakes average, No./L	Mt. Elbert Forebay average, No./L
Diaptomus	6.1	13.5
Cyclops	11.9	3.3
Rotifers	53.5	3.0
Daphnia	0	4.6
Bosmina	0	0.1
Nauplii	19.5	10.3
Total	91.0	34.8

Benthic colonization of large powerplant forebays has been documented. Olson, et al. (1974) [7], showed that the benthic organisms found in Lake Michigan colonized the Ludington Pumped-Storage Powerplant Forebay shortly after operation began. Colonization of Mt. Elbert Forebay was very sparse, densities and mass of benthic organisms remained far below the Twin Lakes numbers. Table 11 summarizes those differences. Colonization may have been hindered by Mt. Elbert Pumped-Storage Powerplant not being in operation. The continual transfer of water during operation may benefit benthic colonization, although the chironomid population should have been able to populate the forebay without transfer. The hardpacked clay substrate was likely the reason for the low abundance of benthic fauna in the forebay. Brinkhurst (1974) [8] presents data that indicate substrate is an important component of benthic production.

Anticipated Effects of Powerplant Operation

It is anticipated that there will be some changes in the ecology of both Mt. Elbert Forebay and Twin Lakes from pumped-storage operation. The goal of research at Twin Lakes is to quantify these changes. The following are some speculations about the forebay based on available data.

Table 11.–*Density and mass comparisons of benthos. Mt. Elbert Forebay and Twin Lakes, Twin Lakes, Colorado, 1979*

	Twin Lakes		Mt. Elbert Forebay	
	No./m^2	g/m^2	No./m^2	g/m^2
April				
Chironomids	1867	1.1663	43	0.0069
Oligochaetes	603	0.2250	43	0.0099
August				
Chironomids	2256	2.8094	153	0.01366
Oligochaetes	458	0.1426	0	0

Temperature stratification of the forebay is questionable when powerplant operation begins. During operation, greater forebay depth might make summer stratification possible; however, it is still unknown how movement of water caused by pumping and generating will affect stratification. Temperature differences between Twin Lakes and the forebay could influence stratification. If colder water were pumped to the forebay from Twin Lakes, it would sink to the bottom of the forebay and artificially induce a stratification. Warmer water being pumped up would remain on top and, likewise, induce a stratification.

Formation of ice cover on the forebay will be delayed after operation begins due to its greater depth and volume during operation. Both the forebay and Twin Lakes should have open water adjacent to the inlet-outlet structure, and continual change in water surface elevation will cause breaks and pressure ridges on the ice covers.

Chemically, the two bodies of water should approach isoconcentrations of dissolved chemicals as time progresses. Any leaching of higher amounts of heavy metals should eventually be diluted between the two systems. The forebay should remain high in any chemicals conveyed from Turquoise Lake via the Mt. Elbert Conduit and from the polyethylene liner. However, it is speculative.

Active daily discharge of organisms into Mt. Elbert Forebay (and Twin Lakes) from Turquoise Lake (Sugar Loaf Dam) will affect the colonization of both the forebay and Twin Lakes.

Perhaps the most interesting observation will be the cladoceran population. Cladocerans are found rarely in Twin Lakes because of the presence of the freshwater shrimp *Mysis relicta*. However, cladocerans, especially *Daphnia*, are common in Turquoise Lake which will divert water into the forebay and Twin Lakes. If *Mysis* become established in the forebay, predation could occur there. If enough cladocerans are contributed from Turquoise Lake, the forebay could act as a "nursery" to supply cladocerans to Twin Lakes.

Future Studies

Bureau of Reclamation limnological studies at Twin Lakes and Mt. Elbert Forebay will continue after powerplant operation commences. Routine biweekly surveys for collecting physical, chemical, and biological data will be augmented by the use of five continuous monitoring stations (fig. 14). Four will be located on Twin Lakes, and one on the forebay (fig. 3). They will assist data collection by filling gaps in both the limnological and meteorological data. A series of nets and floats will be located in both the forebay (fig. 15) and Twin Lakes to determine fish mortality and transport. These ongoing studies should help determine the actual ecological effects of the pumped-storage powerplant.

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Note: From November 1979 to May 1981, the Bureau of Reclamation was known as the Water and Power Resources Service; consider the names synonymous in this Bibliography.

APPENDIX

The following six tables contain the physical, chemical, and biological records of Mt. Elbert Forebay, 1978-79.

Appendix table 1.–*Physical parameters of Mt. Elbert Forebay, 1978-79*

	1978				1979															
	11-3	11-16	12-1	12-20	1-11	2-2	2-21	3-13	4-5*	4-19	5-16	6-6	6-22	7-5	7-19	8-3	8-15*	9-7	9-14	9-21
Time	0900	0845	-	1000	1230	0945	1030	1130	1155	0900	1350	-	-	-	-	1200	1025	0935	-	1240
Air temp. (°C)	-	27	-	-12	2	-	-	5	-	-	12	-	18	-	24	-	-	13	-	-
Water temp. (°C)	5	0	-	-	-	-	-	0	1.4	-	1	-	15	-	16	-	16.5	14	-	-
Snow depth (cm)	-	-	9	30	23	5	25	46	25	-	-	-	-	-	-	-	-	-	-	-
Ice thickness (cm)	-	4	15	60	46	64	66	56	74	69	-	-	-	-	-	-	-	-	-	-
Conductivity (μS/cm)	95	93	110	118	107	106	110	110	109 104	114	114	94	86	96	99	97	95 76	97	85	92
pH (lab)	7.5	7.7	7.7	7.6	7.4	8.0	7.8	7.8	7.8 7.8	7.8	7.0	6.9	7.73	7.20	6.60	7.65	7.60 7.70	7.8	7.1	7.0

* Sampled at depths of 1 and 3 meters.

Appendix table 2.–*Major ion analyses of Mt. Elbert Forebay, 1978-79*

	1978				1979															
	11-3	11-16	12-1	12-20	1-11	2-2	2-21	3-13	4-5*	4-19	5-16	6-6	6-22	7-5	7-19	8-3	8-15*	9-7	9-14	9-21
Calcium (mg/L)	12.8	13.6	12.8	14.4	14.4	15.2	14.4	14.4	14.4 14.4	16.0	14.0	13.8	13.2	13.2	14.0	13.6	13.6 13.0	13.6	12.2	13.6
Magnesium (mg/L)	3.9	1.95	2.93	1.95	0.976	1.46	1.95	1.95	2.93 2.44	1.46	2.68	1.83	1.22	1.71	1.71	1.34	0.244 0.976	0.976	1.83	2.8
Sodium (mg/L)	2.76	2.30	1.84	1.84	1.84	1.84	1.84	2.30	1.84 1.64	2.30	1.84	1.84	1.84	2.53	2.53	3.22	3.22 3.45	2.53	2.30	2.3
Potassium (mg/L)	2.35	2.35	1.56	1.95	1.95	1.95	1.95	1.95	1.95 1.95	1.95	1.95	1.95	1.56	1.95	0.782	1.95	1.95 1.95	1.95	1.56	1.9
Carbonate (mg/L)	0	0	0	0	0	0	0	0	0 0	0	0	0	0	0	0	0	0 0	0	0	0
Bicarbonate (mg/L)	56.7	35.4	36.6	36.6	36.6	37.2	36.6	36.6	37.2 36.6	39.0	35.4	35.4	30.5	34.8	34.2	34.8	36.0 36.0	36.0	33.6	38.4
Sulfate (mg/L)	13.4	14.4	16.8	16.8	16.3	18.2	18.2	14.9	17.8 16.8	17.8	17.8	17.8	14.4	15.8	13.9	19.2	10.6 10.1	13.9	17.8	19.7
Chloride (mg/L)	2.84	0.71	3.20	0.355	0.355	0.71	2.13	1.07	2.13 2.84	2.13	1.78	1.78	2.84	1.78	2.84	2.13	2.13 2.84	0.355	0.355	2.13
Anions + Cations (mg/L)	94.8	70.7	75.7	73.9	72.4	76.6	77.1	73.2	73.2 76.9	80.6	75.4	75.4	65.6	71.8	69.9	76.2	67.7 68.3	69.3	69.6	80.9
TDS/105 °C (mg/L)	56.0	86.0	50.0	62.0	80.0	64.0	86.0	50.0	72.0 84.0	72.0	76.0	102.0	62.0	44.0	54.0	68.0	60.0 54.0	66.0	76.0	82.0

* Sampled at depths of 1 and 3 meters.

Appendix table 3.–*Trace metal analyses of Mt. Elbert Forebay, 1978-79* †

	1978				1979															
	11-3	11-16	12-1	12-20	1-11	2-2	2-21	3-13	4-5*	4-19	5-16	6-6	6-22	7-5	7-19	8-3	8-15*	9-7	9-14	9-21
Copper (mg/L)	0.002	0.0025	0.004	0.002	0.05	0.01	0.016	0.017	0.001 N.D.	0.0073	0.0114	0.0052	0.0005	0.0005		0.0012	0.018 0.0186	0.004	0.002	0.006
Iron (mg/L)	0.53	0.41	0.33	0.27	0.27	0.21	0.10	0.15	0.20 0.28	0.68	0.31	0.17	0.19	0.14		0.38	0.24 0.31	0.48	0.80	
Lead (mg/L)	0.002	0.0015	0.002	0.002	0.04	0.015	0.0134		N.D. N.D.	N.D.	0.0082	0.0027	0.20	N.D.		0.0012	0.0083 0.0067	N.D.	N.D.	0.019
Manganese (mg/L)	0.01	N.D.	0.01	N.D.	0.01	N.D.	N.D.	N.D.	N.D. N.D.	N.D.	N.D.	N.D.	N.D.	N.D.		N.D.	N.D. N.D.	0.01	0.01	0.05
Zinc (mg/L)	0.006	0.045	0.082	0.009	0.43	0.032	0.025	0.065	0.004 0.005	0.004	0.001	N.D.	0.0032	0.0562		0.0424	0.0455 0.0300	0.01	0.01	N.D.

* Sampled at 1- and 3-meter depths.
† Total metal concentrations include both dissolves and particulate
N.D. (nondetectable).

Appendix table 4.–*Nutrient analyses of Mt. Elbert Forebay, 1978-79 (mg/L)*

	1978				1979															
	11-3	11-16	12-1	12-20	1-11	2-2	2-21	3-13	4-5*	4-19	5-16	6-6	6-22	7-5	7-19	8-3*	8-15	9-7	9-14	9-21
Total phosphorus	N.D.	N.D.	0.012	0.003	0.006	0.006	0.009	0.003	0.003 0.003	N.D.	0.008	-	N.D.	N.D.	N.D.	N.D.	0.010 0.015	0.005	N.D.	N.D.
Ortho phosphate	N.D.	N.D.	N.D.	N.D.	0.002	0.006	N.D.	N.D.	N.D. N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	 0.015	N.D.	N.D.	N.D.
Ammonia (NH_3)	N.D.	N.D.	0.015	N.D.	0.01	N.D.	N.D.	N.D.	0.20 0.05	N.D.	0.02	0.01	0.02	0.02	N.D.	N.D.	0.04 0.04	N.D.	N.D.	N.D.
Nitrate (NO_3)	0.05	N.D.	N.D.	N.D.	0.02	0.04	0.048	0.04	0.005 0.005	0.17	0.40	0.07	0.06	0.05	0	0.03	0.02 0.02	0.10	0.10	N.D.
Nitrite (NO_2)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.005	N.D.	N.D. N.D.	0.01	0.005	N.D.	N.D.	N.D.	N.D.	N.D.	N.D. N.D.	N.D.	N.D.	N.D.
Total Kjeldahl Nitrogen (TKN)	N.D.	0.12	0.09	0.12	0.15	0.15	0.30	0.15	N.D. N.D.	N.D.	0.270	0.330	0.210	0.240	0.360	0.360	0.120 0.420	N.D.	0.270	0.12

* Sampled at 1- and 3-meter depths.
N.D. (nondetectable).

Appendix table 5.–*Phytoplankton found in Mt. Elbert Forebay, 1978-79 (No./L)*

	1978				1979														
	11-3	11-16	12-1	12-20	1-11	2-2	2-21	3-13	4-5	4-19	5-16	6-6	6-22	7-5	7-19	8-3	8-15	9-7	9-14
Dictyospherm	-	-	-	-	-	-	-	-	-	-	-	-	-	-	108	3	-	-	-
Asterionella	157	238	57	-	-	-	50	-	-	43	30	10	-	3	-	-	-	-	-
Oscillatoria	12	15	-	-	-	-	-	-	-	-	2	-	-	9	-	-	-	-	5
Synedra	4	18	6	-	-	-	-	-	-	24	51	10	11	-	18	25	22	22	21
Dinobryon	-	3	-	-	-	-	41	-	-	-	-	-	-	5	-	-	-	-	-
Fragilaria	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	5	-	4	-

Appendix table 6.–*Zooplankton found in Mt. Elbert Forebay, 1978-79 (No./L)*

	1978				1979														
	11-3	11-16	12-1	12-20	1-11	2-2	2-21	3-13	4-5	4-19	5-16	6-6	6-22	7-5	7-19	8-3	8-15	9-7	9-14
Diaptomus	2	14	5	-	-	18	27	7	7	19	4	2	70	7	23	2	38	1	4
Cyclops	3	16	6	-	-	1	3	2	3	1	-	1	6	1	5	2	1	1	3
Nauplii	5	8	3	-	-	-	-	-	1	-	1	35	106	8	16	5	8	3	7
Kellecottia	2	1	1	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	2
Polyarthra	12	21	0.3	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-
Daphnia	2	1	1	-	-	1	-	-	2	-	1	14	2	4	49	3	10	4	1
Keratella	-	1	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	1
Bosmina	-	0.3	0.3	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-

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* From Nov. 1979 to May 1981, Bureau of Reclamation was known as the Water and Power Resources Service.

GPO 836 – 578

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